Analysis of oscillations and kinematics of the coronal rain observed with IRIS

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Implications for coronal heating and magnetic fields
from coronal rain observations and modelling

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Observations and Data processing

Hinode-IRIS-SST coordination (HOP 262), August 2014 observing campaign
⇒ SST, EIS, SOT data also available

Focus on AR 12151
⇒ event from the 25/08/2014:

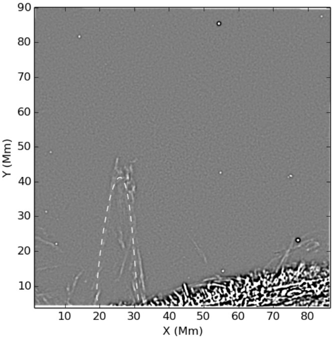
Duration: 7:46 - 10:30
OBSID: 3820009453
Large sit-and-stare
Level 2 SJI in Si IV line (1400 Å)
Cadence: 19 s

Observations and Data processing

- Focus on coronal loop in the foreground - visible during most of the sequence, coronal rain in the second third
- Visible flows - most of upward flow occurs in the remote leg, rain mostly in the nearby leg
- Asymmetry in the rain flow direction arising when superimposed siphon flow and coronal rain
- Other loops intersecting the axis - avoid contamination

Observation limited to
single vantage point
$\Rightarrow$ account for projection effects

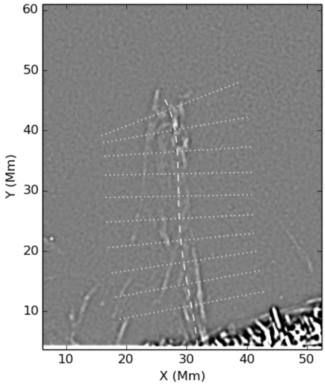
Loop geometry estimates:
Loop radius: 41 Mm
Loop plane - LOS angle: 9°



Observations and Data processing

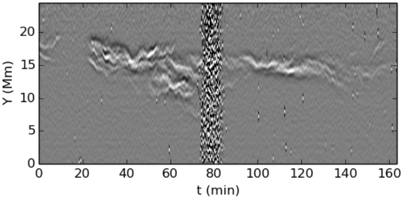
Pre-processing:

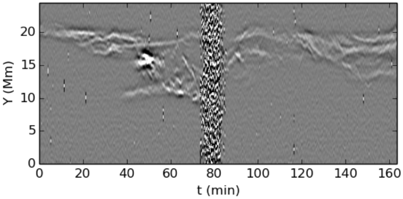
- Level 2 data - basic wavelength calibration; dark, flat field already subtracted
- Reduce noise by using Mexican Hat wavelet filtering
- Set up 10 regularly spaced slits perpendicular to the loop axis to trace oscillations at different positions along the loop
- Stack data cuts along the slit at each time step to extract time-distance plots
- Data in each slit superimposed over 30 pixels in longitudinal direction to detect oscillations of small blobs



Transverse Oscillations

- Multiple transverse oscillations visible along the whole loop length
- 150 oscillations observed in total
- Obtain detrended displacement time series for each oscillation
- Fit the time series with function $\xi(t) = \xi_0 sin(\omega t + \Phi)$ to determine oscillation parameters





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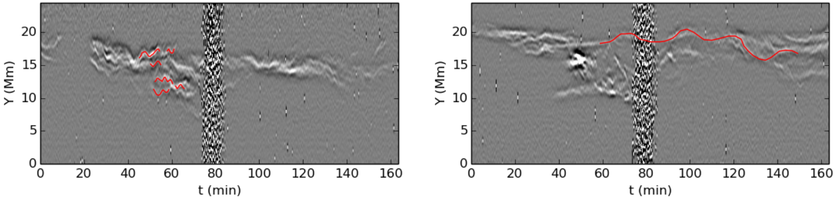
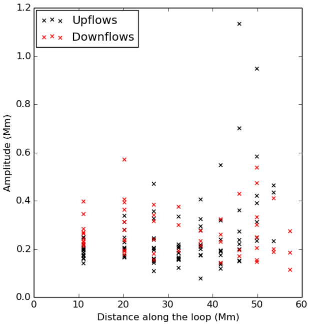
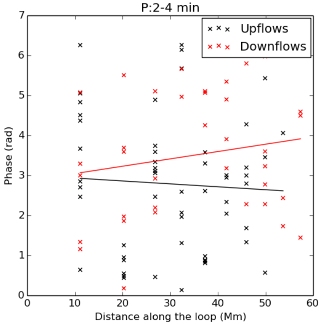


Transverse Oscillations

- No clear trend in amplitude as a function of distance along the loop - complicates harmonic determination (large uncertainties due to strand thickness)
- Clear in-phase oscillation patterns for groups of condensations
- Two populations: small scale and large scale oscillations
- Estimated expected phase gradients for given period of oscillation if travelling wave
- Large scale oscillations - phase shift too small to detect for given duration of observed data set
- Small scale oscillations - no such trends show in the phase-distance plot ⇒ standing wave





Two different regimes of transverse oscillations:

Small scale oscillations traced by coronal rain observed previously (Antolin & Verwichte, 2011):

- Average period: 3.4 min
- Amplitudes from 0.1 Mm ($\sim$ resolution limit) to 0.6 Mm, decreasing near the footpoints
- Characteristics similar to those reported in previously published work
- Observed along the whole loop length
- Most prominent near the loop apex
- No significant damping over the duration of the observation
- No phase shift observed - standing wave, in-phase oscillations of nearby strands - kink mode (monolithic waveguide or multiple strands) or torsional Alfvén mode scenario?
- Possible Sources:
  - No events in AR12151 on the day of observation, C class flare in AR 12150, series of C class flares in AR 12149, too far to have significant effect? Also event-excited oscillations undergo rapid damping, which is not observed in this case?
  - Decay-less low amplitude oscillations - loop response to continuously operating non-resonant driver (Nisticò et al. 2013)
  - Interactions with neighbouring loops?
  - Condensations themselves triggering the oscillations?

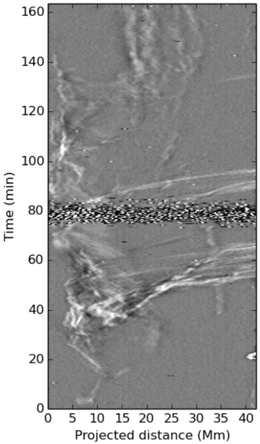
Two different regimes of transverse oscillations:

Large scale oscillations:

- Average period: 24 min
- Amplitudes around 1 Mm
- Traced by upflowing material in remote loop leg
- Most pronounced near the footpoint and fading higher along the loop
- Most likely caused by a different (transient) mechanism operating near the footpoints

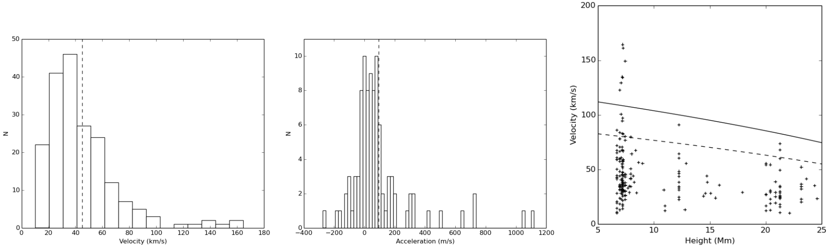
Kinematics

- Tracked 18 blob paths in longitudinal direction
- Total of 115 plasma blobs were tracked, 18 blobs in upward flows, 97 condensations
- Extract individual blob paths from each timeslice
- Get time-distance plots (spatial dimension = projected longitudinal distance from the loop apex), account for projection effects
- Determine velocity at the beginning and end of path of each blob, deduce acceleration



Kinematics

Focus on falling condensations:



Broad distribution of velocities, individual velocity and acceleration profiles
$\Rightarrow$ both acceleration and deceleration processes

Average velocity: 44.91 $km.s^{-1}$
Average acceleration: 94.96 $m.s^{-2}$
$\langle g_{eff} \rangle = \frac{2}{\pi} \int_0^{\pi/2} g_\odot cos\theta(s) ds$
Average effective gravity along the loop: $\langle g_{eff} \rangle$ =174 $m.s^{-2}$

$\Rightarrow$observed values significantly lower - sub-ballistic fall rates previously reported (eg. De Groof et al. 2004, Antolin & Verwichte 2011, Antolin & Rouppe van der Voort 2012)

Kinematics

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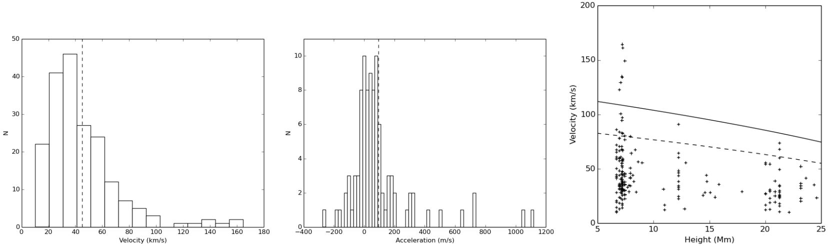

Possible sources of deceleration:

- Gas pressure gradients?
- Helical magnetic fields (doesn't seem so from the observations if assuming rain to be a good tracer, also stability issues)
- Interaction with hotter and denser transition region plasma/shocks (but deviation from free fall speed observed along whole loop length?)
- Can be explained by the presence of oscillations - ponderomotive force (most likely)

Conclusions

- Analysed oscillations and kinematics of coronal rain observed in SI IV line by IRIS
- Detected 150 oscillations in total along the whole loop length
- Two regimes of transverse oscillations:
    - Small scale oscillations - reported previously, typical periods 3 min, amplitudes below 0.6 Mm, most prominent near loop apex, no damping - continuously operating driver
    - Large scale oscillations - periods around 24 min, amplitudes around 1 Mm, most prominent near footpoints, transient driving mechanism
- Tracked 115 plasma condensations along their paths to analyse dynamics
- Broad distribution of velocities with mean 45 $km.s^{-1}$
- Motion significantly sub-ballistic with mean acceleration 95 $m.s^{-2}$
- Possible reason for the observed deceleration: ponderomotive force?
- Future work - modelling